NASA Dryden Flight Research Center

"Performance Seeking Control Excitation Mode"

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Abstract

Flight testing of the Performance Seeking Control (PSC) Excitation mode was successfully completed at NASA Dryden on the F–15 highly integrated digital electronic control (HIDEC) aircraft. Although the Excitation mode was not one of the original objectives of the PSC program, it was rapidly prototyped and implemented into the architecture of the PSC algorithm, allowing valuable and timely research data to be gathered. The primary flight test objective was to investigate the feasibility of a future measurement–based performance optimization algorithm.

This future algorithm, called AdAPT, which stands for Adaptive Aircraft Performance Technology, generates and applies excitation inputs to selected control effectors. Fourier transformations are used to convert measured response and control effector data into frequency domain models which are mapped into state space models using multiterm frequency matching. Formal optimization principles are applied to produce and integrated, performance optimal effector suite. The key technical challenge of the measurement–based approach is the identification of the gradient of the performance index to the selected control effector. This concern was addressed by the Excitation mode flight test.

The AdAPT feasibility study utilized the PSC Excitation mode to apply separate sinusoidal excitation trims to two controls, one aircraft, inlet first ramp (cowl), and one engine, throat area. Aircraft control and response data were recorded using on–board instrumentation and analyzed post–flight. Sensor noise characteristics, axial acceleration performance gradients, and repeatability were determined. Results were compared to pilot comments to assess ride quality.

Flight test results indicate that performance gradients were identified at all flight conditions, sensor noise levels were acceptable at the frequencies of interest, and excitations were generally not sensed by the pilot.

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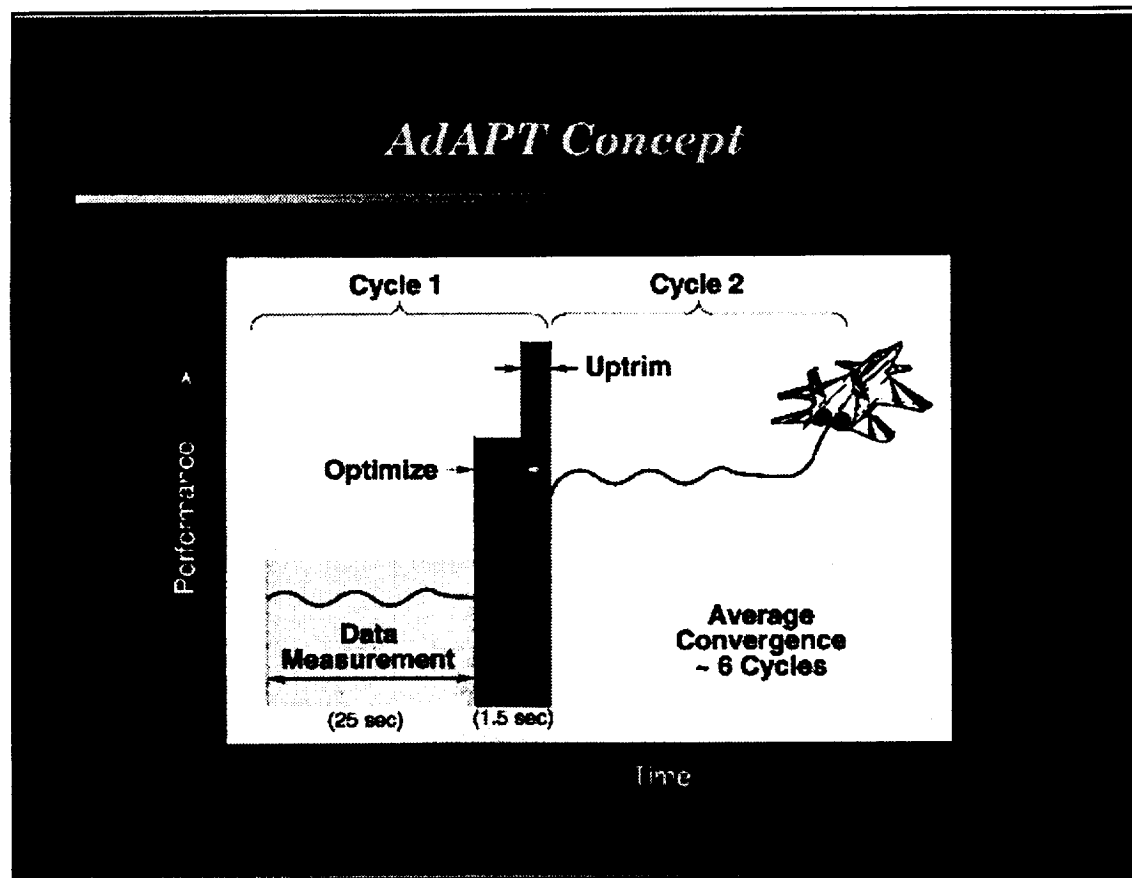## "Performance Seeking Control Excitation Mode", page 2

PSC Excitation Mode Testing

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The PSC Excitation Mode was not part of the original PSC algorithm, but was added to investigate the feasibility of an adaptive measurement–based, algorithm that optimizes the aircraft and propulsion system in real–time during quasi–steady–state operation. The most important technical challenge for the measurement–based approach will be identifying the performance gradients without excessively disturbing the aircraft flight path. Other issues with this approach include the effects of noise or other extraneous inputs on the identification and the threshold sensitivity of the sensors. This new algorithm, Adaptive Aircraft Performance Technology (AdAPT), will be flight tested on a future program on a different aircraft.

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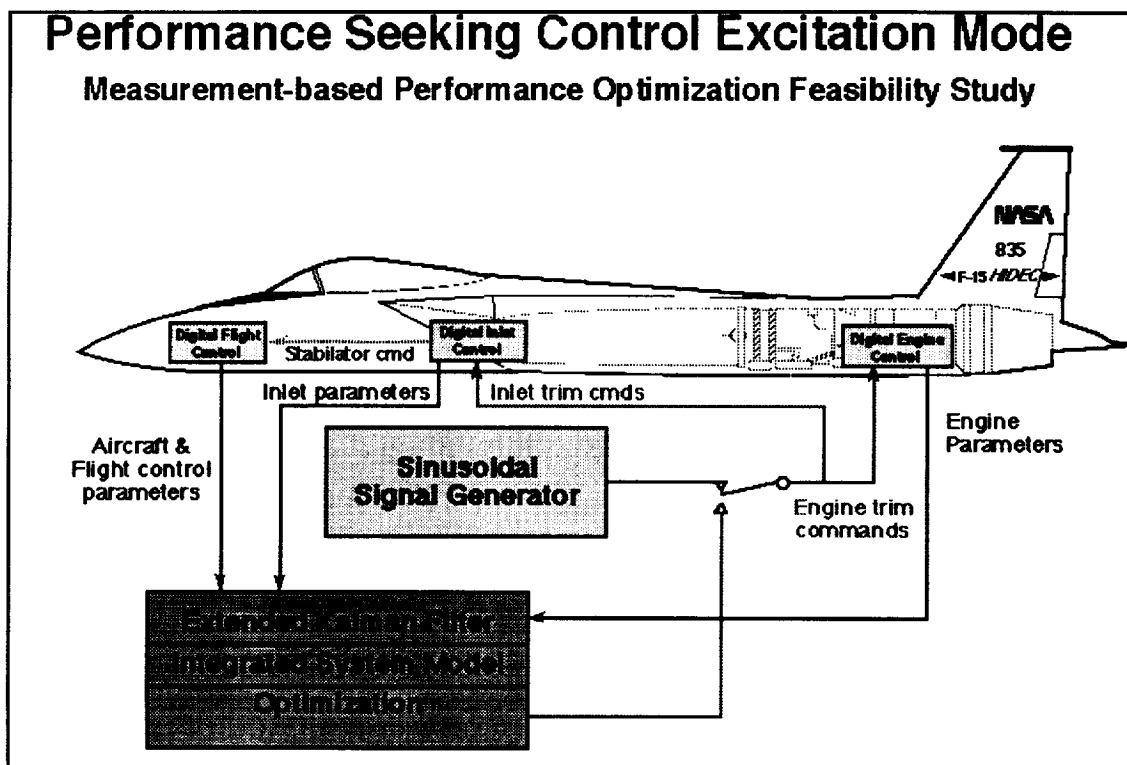## "Performance Seeking Control Excitation Mode", page 3

PSC Excitation Mode Implementation

The implementation of the PSC Excitation Mode was based on the Minimum Fuel Mode. This allowed the operation of the algorithm at any power lever angle setting. PSC trim adders and multiplier options zeroed all trim outputs of the optimization and applied sinusoidal trims to the nozzle throat area and/or the inlet first ramp or cowl. Frequency and amplitude trim characteristics were selected inflight for each control via a variable gain structure. Aircraft controls and acceleration data from three longitudinal accelerometers were recorded on the instrumentation system for analysis postflight.

Maneuvers were flown across the subsonic and supersonic envelope of the F–15. Eleven test maneuvers were flown at nine flight conditions ranging from 0.7 Mach at 10,000 feet to 2.0 Mach at 45,000 feet. The eleven maneuvers were comprised of an amplitude parametric test, a frequency parametric test, and 9 standard tests. The

standard test included an inlet excitation, a nozzle area excitation, and both controls excited simultaneously.

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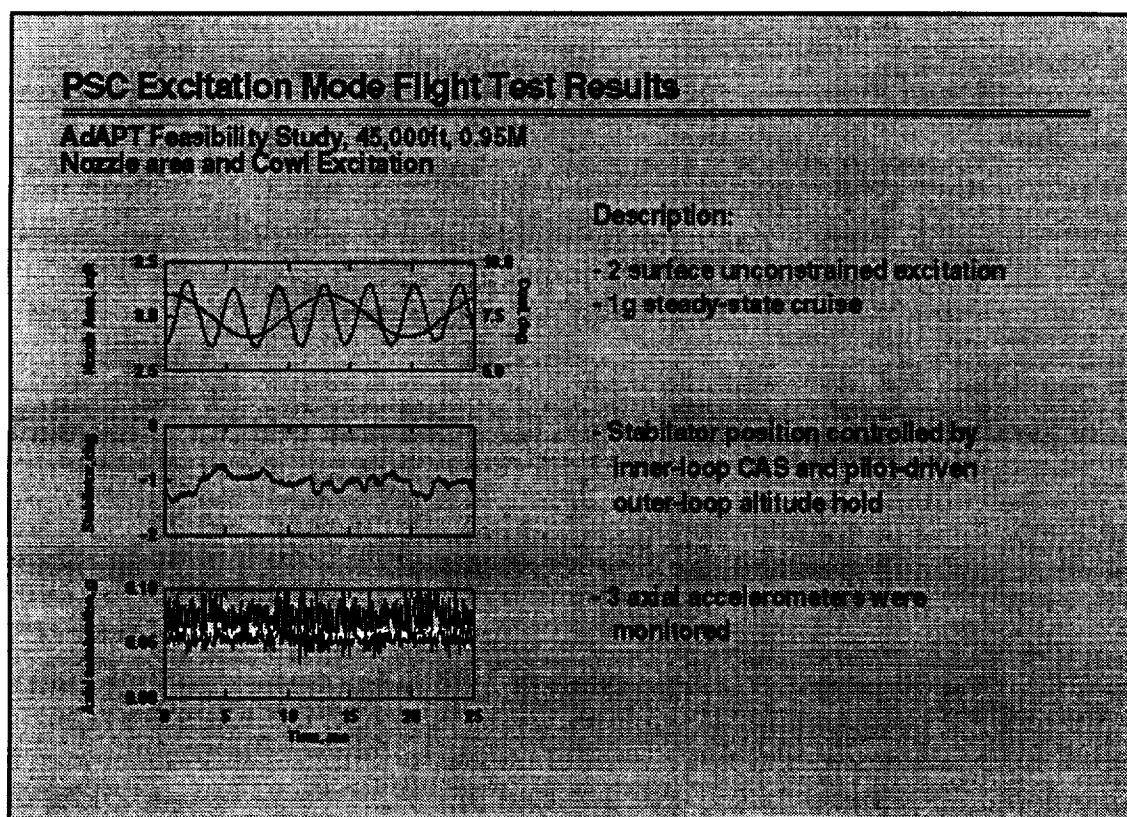## "Performance Seeking Control Excitation Mode", page 4

PSC Excitation Mode Analysis – Time Histories

Time histories are shown for simultaneous cowl (inlet ramp) and throat area excitations at a flight condition of 45,000 feet and 0.95 Mach in the above figure. The first time history shows the excitations of the two controls, cowl and nozzle area; the maneuver lasted 25 seconds. The nozzle area was excited with a period of 12 seconds and an amplitude of +/– 0.2 square feet. The cowl was excited at a shorter period of 3.7 seconds and an amplitude of +/– 2 degrees. The second time history is of the stabilator position, which indicated how the controls are affecting stabilator position and, in turn, drag. The last time history shows the three longitudinal accelerometer traces for the same time period. One accelerometer has a much lower signal–to–noise ratio than the other two.

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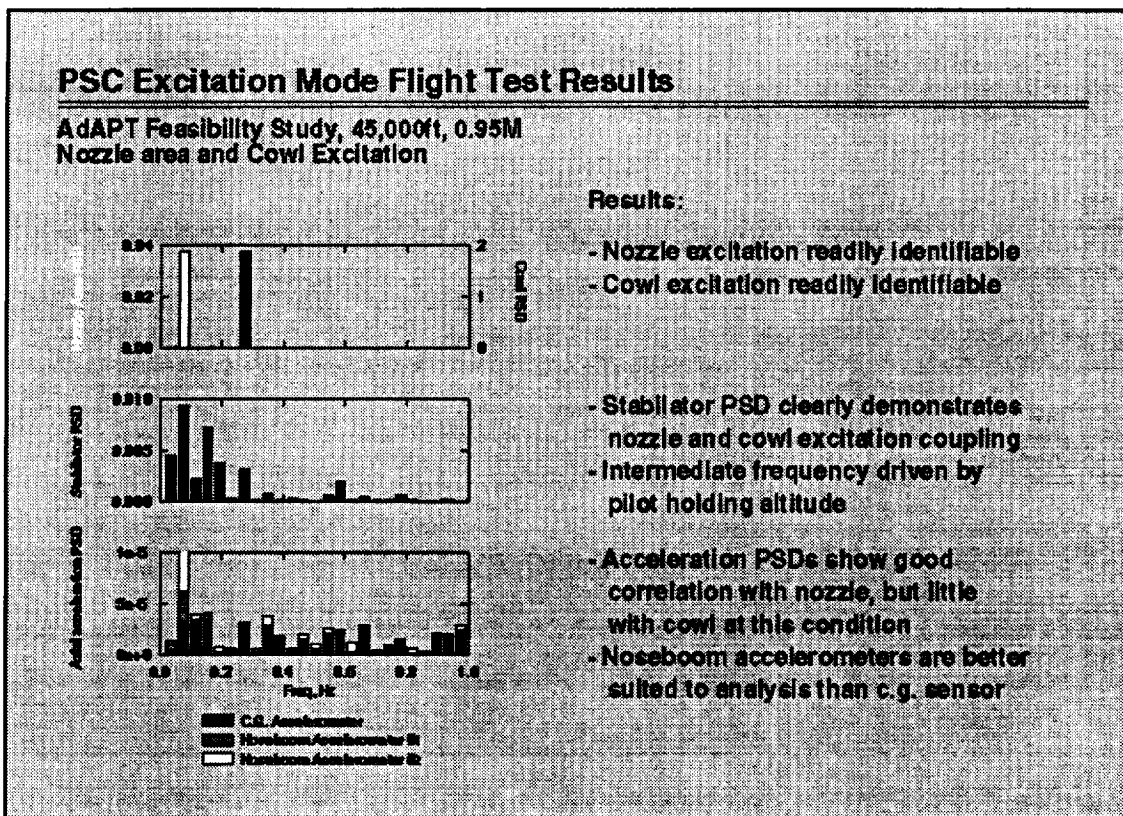## "Performance Seeking Control Excitation Mode", page 5

PSC Excitation Mode Analysis – PSDs

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Power Spectral Densities (PSD, plots of amplitude of the Fast Fourier Transform, FFT, squared versus frequency) for the corresponding signals (see individual signals in previous figure) are presented in the above figure. The first PSD shows the distinct peaks of the two controls with no interference between the two. The second PSD indicates that at this condition the nozzle area had a greater effect on the stabilator drag than cowl. The third PSD indicates that the two noseboom accelerometers clearly sensed the nozzle area excitation, but did not sense the cowl excitation. These PSDs are a direct indication of the quality of the identification of the performance gradients. Also, noise levels were observed to be low to frequencies beyond any planned excitation. By comparison, the c.g. accelerometer had unacceptable performance with high noise levels starting at very low frequencies making the

identification difficult. Overall, the results show that the identification is readily possible and virtually imperceptible to the pilot and not affected by simultaneous excitations.

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PSC Excitation Mode Results

Results   **NASA**

- Gradients were identified at all flight conditions
- Throat area gradients were easily identified at all flight conditions
- Inlet first ramp gradients were identified at high dynamic pressures
- Perturbations were generally imperceptible to the pilot

Measurement-based performance optimization promises significant benefits with low cost

Overall, gradients were successfully identified at all conditions. As expected at low dynamic pressures where the inlet ramp is ineffective, the inlet ramp gradient was within the noise level. At higher dynamic pressures, the inlet ramp gradient was easily identified. The nozzle throat area gradient was identifiable at all conditions. Simultaneous excitations of both controls produced gradients that were nearly identical to those performed

separately. Pilot comments with respect to disturbance to flight path indicated that the excitation was generally not perceptible, and when perceptible, it was insignificant.

The development of measurement–based performance optimization promises to produce significant benefits with little additional cost. This flexible approach allows all aircraft, commercial and military, subsonic and supersonic to attain an optimum configuration.

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"PSC Asymmetric Thrust Alleviation Mode"

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Asymmetric thrust alleviation is the ability to reduce large yaw excursions resulting from thrust asymmetry. This capability is particularly important in high thrust, multi-engine aircraft that experience reduced lateral-directional stability at high dynamic pressure. An example is the F-15E with F100-PW-229 engines, in which structural damage or aircraft departure can occur at high Mach numbers if a single augmentor fails and the rapid yaw excursion is not arrested.

The PSC asymmetric thrust alleviation (PATAL) mode, unlike other methods in use, employs digital communication to detect an augmentor blow-out or fault, and then sends a military power autothrottle command to both engines. The engines remain in primary mode, unless the fault that caused the loss of augmentation was a secondary (SEC) mode transfer. In this case, the good engine remains in primary. The primary objective of testing this mode was to verify that augmentation was canceled quickly enough to avoid unacceptably large yaw excursions.

The PATAL mode was successfully tested at 31,000 ft, Mach 0.93. The mode was expcted to be tested at higher dynamic pressures to measure its effectiveness at reducing yaw excursions following a similated augmentor fault, but the retirement of the HIDEC aircraft precluded this. At the 31,000 ft/0.93 condition, yaw excursions resulting from augmentor-out are small. However, because the time delay of the autothrottle command is independent of Mach number, the actual flight test timing results were none-the-less significant.

Plotted in the figure below is post-flight calculated net thrust versus time following a pilot-initiated secondary mode transfer (with corresponding augmentor cancelation) on the right engine at the above flight condition.
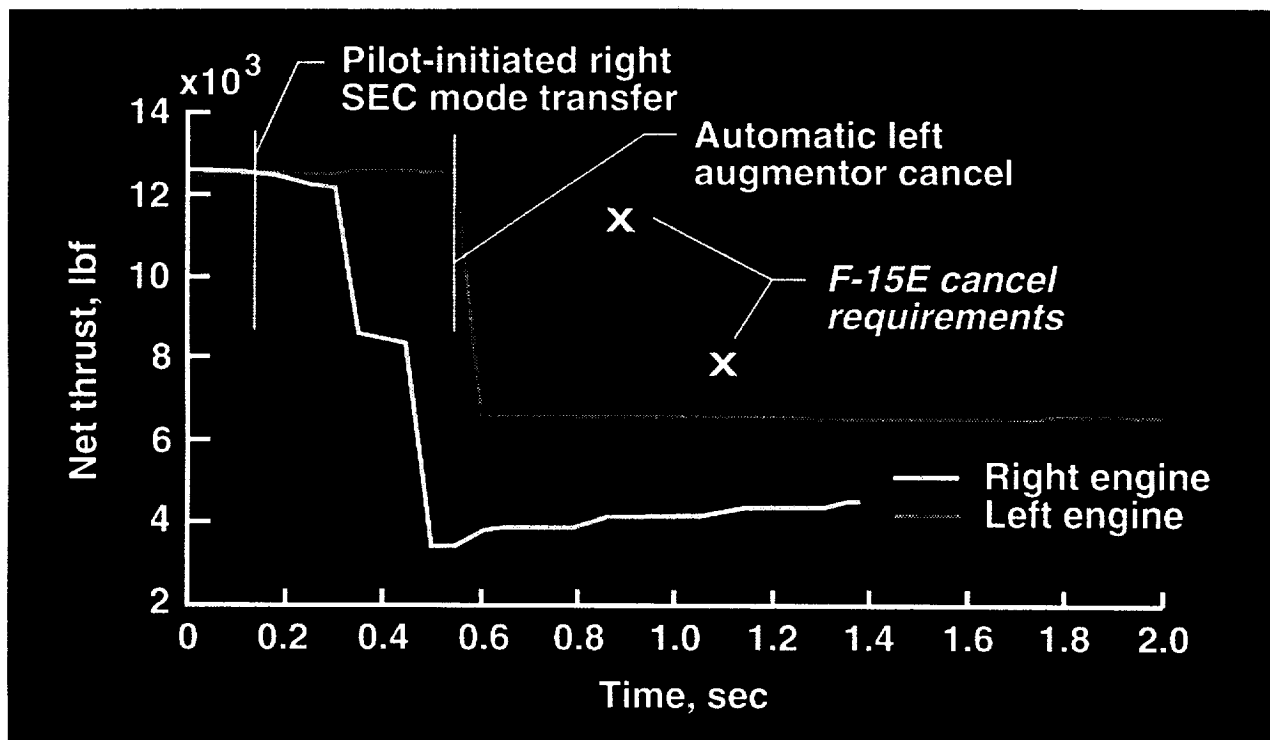
There is no asymmetric thrust problem at 0.9 Mach for the F-15. However, in order to evaluate the timing results, F-15E high dynamic pressure thrust roll-off requirements, extrapolated from 30,000 ft, Mach 2.0, are also plotted on the figure. The F-15 HIDEC results meet these timing constraints.

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The PATAL mode does not utilize the modeling and optimization logic in the PSC algorithm, but it does take advantage of its integrated digital framework. It is another example of the advatages to be gained from integrating avionics and propulsion systems, and it further illustrates the flexibility of the HIDEC aircraft.